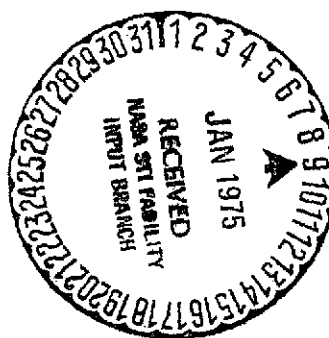


THE HYGIENIC BASIS OF STANDARDS OF ILLUMINATION.
TYPES OF VISUAL FATIGUE.

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16. Abstract An evaluation is made of eye fatigue over a long working period under given lighting conditions. Methods of measuring visual fatigue and the resultant data are discussed. It is found that the method of optical ergography is not very sensitive.			
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§6. THE HYGIENIC BASIS OF STANDARDS OF ILLUMINATION
TYPES OF VISUAL FATIGUE

We will return to the question concerning establishment of /331* illumination standards. To what extent can they be regarded as actual, scientifically based standards, suggested by various illuminating codes? It should be kept in mind that they do not possess a strict basis. They are justified (so long as we ignore economic questions) in part by the general observations of doctor-hygienists and, in part, by the results of specialized laboratory experiments presented above. Similar experiments are quite valuable, interesting, and important. However, they cannot serve as a direct basis to establish exact lighting standards. In the first place, the conditions for laboratory experiments usually differ from the conditions of ordinary working of the eye; the object size is different, the state of adaptation of the eye is different. Most importantly, during laboratory testing of the visual function, the subject usually displays a short, but maximal attentiveness which, in ordinary everyday working of the eye, does not occur. In the latter case, the eye exhibits a somewhat average level of attentiveness, but over a long period of time. In the majority of laboratory experiments concerning the psychophysiology of vision, there is no reference to the fatigability of the eye over long periods of work and under given lighting conditions. From experiments, we know, for example, where the optimum for distinguishing brightness lies, when the visual acuity achieves its maximum, when the speed of visual perception during an increase in illumination achieves a more or less constant value. But on this basis, are we correct

*Numbers in the margin indicate pagination of original foreign text.

to prescribe these values as the best ones for the ordinary working of the eye under industrial conditions? It is not difficult to understand that such a conclusion would not be justified. It is necessary for us to always take into account the fatigability of vision over a long working period under given lighting conditions. In the usual laboratory experiments, no attention is paid to this side of the question, extraordinarily important for lighting technology.

The problem for lighting technology is to find the proper lighting conditions and standards which will allow for maximum productivity over a long period with minimal visual fatigue. In order to establish such standards, obviously, specialized experiments are required that would take into account this last aspect of the question — the fatigability of vision. In this way, the requirement for the necessary hygienic basis for lighting standards leads to the problem of measuring visual fatigue.

The organ of vision — the eye — may be considered, in this connection, to consist of two parts: photosensory and motive. The photosensory apparatus of the eye consists of, on one hand, the photosensitive substances located in the rods and cones, and, on the other hand, the optic centers in the retina and the brain. The motive apparatus consists of all those muscles by means of which the eyeballs move during convergence and divergence of the visual axes and during visual fixation. Also included are the iris muscles which control pupillary diameter and the ciliary muscle which alters the curvature of the crystalline lens, thereby allowing the eye to accommodate to near or far objects. Both the photosensory apparatus and motive apparatus may fatigue (i.e., lower their work capacity). Fatigue of the photosensitive apparatus leads to the appearance

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of light adaptation. As experiments have proven, and as postulated by Lazarev, the decline in photosensitivity of the eye follows an exponential curve. The fall in sensitivity is, for the most part, completed within the first minutes and even seconds after the light impinges on the retina. Afterwards, the sensitivity remains practically constant. The greater the intensity of the light impinging upon the retina, the lower the sensitivity. There is a basis to suppose that the lowering of the photosensitivity of the eye depends not only upon the brightness of the incident light, but as well, upon the size of the retinal image. To the degree that the latter increases in size, the sensitivity becomes correspondingly lower. As concerns the effect of the wavelength, we have already seen that, according to the results of our experiments of three equally bright colors (red, green, and bluish-violet), the least fatiguing is green, the most fatiguing — bluish-violet.

In evaluating the practical import of fatigue of the photosensitive apparatus under the condition of the worker's surroundings, we must recognize them to be of relatively lesser importance than fatigue of the motive apparatus. The photosensitive apparatus, in no time at all, approaches a somewhat stationary condition and does not fatigue any further in this sense. Moreover, if we wished to, first of all, avoid fatigue of the photosensitive apparatus of the retina, we should only have to weaken as far as possible the level of illumination. This would instantly lead to a loss of visual function, not only for light and shadow, but also for discernment of form, i.e., it would be clearly detrimental to visual acuity and to all visual functioning.

The role that the neural segment of the photosensitive apparatus of the eye plays in visual fatigue is still little studied. Bogorlovskiy ([1937]) observed a lowering of the electrical sensitivity of the eye in the course of prolonged visual work, such as sewing of embroidery, reading, sorting of seeds, watching movies, etc. So long as the electrical current does not come in contact with the photosensitive substances of the retina, a lowering of neural excitation in the photosensitive apparatus of the eye occurs.

The motive apparatus of the eye, consisting of the external ocular muscles, the iris muscles, and ciliary muscle, as any muscular apparatus, is also capable of fatigue, i.e., to weakly respond to stimulation in the form of prolonged, excessive tension or frequent repeated changes of tension and relaxation. Such conditions stem precisely from the necessity of the eye to fixate on very close objects, to discern fine details, to fixate moving objects, to frequently alter one's gaze from one object to another and from rapid movement from light into shadow and vice versa. Fatigue of the motive apparatus of the eye may grow in the course of the working day. The conditions of illumination at the place of work contribute to this.

In order to select the best lighting conditions from the hygienic point of view, one must obviously be able to somehow judge the degree of tiredness of the eyes, i.e., one must know how to measure visual fatigue.

§7. METHODS OF MEASURING VISUAL FATIGUE AND RESULTANT DATA. VISIBILITIMETRIC METHOD.

There exists a series of subjective symptoms of eye fatigue: the 'diffuseness' of everything in the field of vision, rheumatic pain in the eyes. Obviously, however, these symptoms do not

impart a quantitative character to the fatigue. Attempts at quantification led to the elaboration of a whole series of methods of measuring visual fatigue.

We tried to measure the sensitivity of the eye to light, its ability to distinguish brightness (distinctive sensitivity) and visual acuity. The first time, the test was conducted prior to fatiguing work and then, afterwards. From comparison of the results, we hoped to be able to judge the fatiguing effect of the work. The experiments, however, revealed that the sensitivity to light and the distinctive sensitivity do not appear to be functions which visual fatigue would affect to any noticeable degree [Ferree]. Bogoslovskiy, it is true, noticed somewhat of an increase in the light thresholds in the course of visual work. The experimental data of Shubovaya did not reveal a decline in distinctual sensitivity after 3 — 4 hours of exhausting visual work in weak lighting. The usual test of visual acuity likewise revealed little fatigue of the organ of sight [Ferree], although according to the data of other researchers, everything to a certain degree reflects it [Cholin, Markstein, Neustadt].

The range of accommodation was also used as an index of visual fatigue. The experiments of Baur, supposedly finding a consistent change in the range of accommodation following work (an increase) did not, however, find confirmation in the more thorough experiments of Kimura. Independently of these last results, the simultaneous approach of the near point and removal of the far point that Baur allegedly observed is not understandable. /334

Recently, the effect of fatigue on a whole series of basic optical values was studied statistically [Gassovskiy and Samsonova] in the laboratory of physiological optics of the State Optical Institute in Leningrad. As a result of studying three score or

more individuals, it was established that visual fatigue involves, in the majority of cases, movement of the far point towards the eye; the position of the near point, meanwhile, was on the average unchanged. Thus, it should be realized that fatigue acts to decrease the range of accommodation.

We believe that experiments on the involuntary reactions of the visual apparatus would prove more revealing than tests of short duration, dependent upon arbitrary attentiveness.

The test of the so-called muscular balance of the eyes is most relevant here, meaning the position that contains the visual axes of both eyes in the absence of a binocularly-fixated object. In some individuals, the tendency of the visual axes to deviate outward predominates (exophoria); in others — the tendency to converge (esophoria). Certain observations tend to convince us that visual work acts to change the initial muscular balance. According to the data of Gassovrskiy and Samsonova, this change is in the direction of increased esophoria. There is a further indication that fatigue can affect even the pupillary reflex: the pupil becomes more constricted than in a non-fatigued eye [Couvreaux]. However, dilation of the pupil was observed in the experiments of Luckiesch and Moss, and also Grassoovskiy and Samsonova. Deserving of attention are facts established in the laboratory of Meshkov concerning the effect of brightness on the fatigued eye and the length of successive images in the fatigued eye. The fatigued eye, as it turned out, was to a greater extent subject to blinding than the unfatigued eye [Bryullova and Meshkov]. Successive images disappear more slowly in the fatigued eye than in the unfatigued eye [Zolin].

The Leningrad ophthalmologist Katz, as long ago as 1895, suggested recording the number of times the eye blinked in one minute as a means of determining the degree of visual fatigue. The point being that blinking produces a momentary darkening of the retina and strengthens the blood circulation in the eye vessels. As a consequence, the eye is able to rest somewhat. The greater is the fatigue, the more the eye blinks. To illustrate this dependency, one may cite the following data, gathered by Katz.

Type of work (reading)	Blinking frequency/min (average)	/335
Direct lighting. Does not shine into eyes. Light output — 12 luxes	1.8	
Open filament of the lamp. Output — 12 luxes	2.8	
Clearly insufficient light output	6.8	

A later test of this method by Newhall showed, however, that the frequency of blinking depended on a great number of factors apart from visual fatigue: accommodation, brightness of the observed surface, the dampness of the cornea, the subject's interest in what is being observed, and some other points. Our observations corroborate the data of Newhall. Recently, the method of counting the number of eye blinks was reapplied by Luckiesch and Moss [1939]. According to their observations, this method may be applied successfully to characterize the quality of lighting conditions. Their data are presented below.

Light output (in foot-candles)	1	10	100
Number of blinks in the first and last 5 minutes of reading	35 - 60	35 - 46	36 - 39
Increase in blinking in the final 5 minutes (in %)	71.5	31.4	8.3

Above, we see that the short methods of testing are bad in that they may entirely depend upon the rapidly shifting exertions of the subject. Therefore, the attention of contemporary psychophysicologists, concerned with the problem of visual fatigue, must be directed to the elaboration of methods taking into account the degree to which the eye can support a definite level of efficiency. This is exactly the method for determining the "constancy of clear vision" proposed by Ferree and Rand.* This method consists in the following. The subject is asked to fixate, in the course of three minutes, upon some small and difficultly discernible detail drawn on a plate. Such a detail may be a gap in a straight line or a break in the ring of Landolt, etc. In similar conditions, the detail is clearly visible to the subject or diffuse in his eyes, and becomes unclear. The subject must, by means of some signal (for example, pressing on a reactive key) indicate all those moments when the detail is no longer clearly visible to him and, equally, all those moments when it again becomes sharp. These signals are mechanically recorded on a smoked tape rotating on a drum with the time being recorded in parallel or simply marked with a stopwatch by the experimenter himself. At the end of the experiment, the sum is taken of all the times in which the detail was clearly visible. The relationship of the entire length of time in which the detail was distinct to the length of the entire experiment or to the entire length of time in which the detail was indistinct is taken as an index of the constancy of clear vision.

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*This method is described by the authors in a series of articles published primarily in the Transact. Illum. Eng. Soc., beginning with 1913. The method elicited criticism on the part of Luckiesh; Cobb and Moss, which in turn gave rise to wordy and methodical replies on the part of Ferree and Rand, defending the validity of the method when the subjects are sufficiently trained and the effects of adaptation and fatigue are taken into account (see Luckiesh, M, P. Cobb, and F. Moss, Trans. Illum. Eng. Soc., Vol. 22, No. 2, 1927). The experiments of Cravath also confirmed the suitability of Ferree's method (Cravath, Trans. Ill. Eng. Soc., 1914, p. 1036).

It is useful, utilizing the method of Ferree and Rand, to take into account likewise the number of times the vision changed from clear to unclear and vice versa; in many individuals, the growth of visual fatigue is expressed primarily in the increased frequency of these changes. Success when using Ferree's method requires a certain degree of training on the part of the subject, a sufficient pause (about 15 — 20 minutes) between separate trials, and a constancy of eye adaptation. At the present time, a significant number of experiments are being conducted using this method by Ferree and Rand themselves in America, and by us in Moscow. The general picture provided by the data convinces us that the degree of "constancy of clear vision" may serve as an indicator of greater or lesser visual fatigue. The rate of decline of this constancy (in the course of the experiment) parallels the perfection or imperfection of the lighting conditions.

In the absence of any visual work, the constancy of clear vision remains unchanged throughout the day. Relevant to this are the special experiments of Semenovskaya, conducted by our invitation in the laboratory of physiological optics of the All-Union Electrotechnical Institute in Moscow.

It is possible to ascertain the uninterrupted decline in the "constancy of clear vision" from hour to hour over the length of visual exertion. In Figure 215 are presented graphs [Shubovaya] of a study of visual fatigue in engravers and watchmakers working for four hours under some constant conditions of illumination. Above the descending curves is presented a straight, horizontal line, obtained by Semenovskaya during determination of the constancy of clear vision in individuals spending an entire day under definite lighting conditions, but not doing any kind of special visual work.

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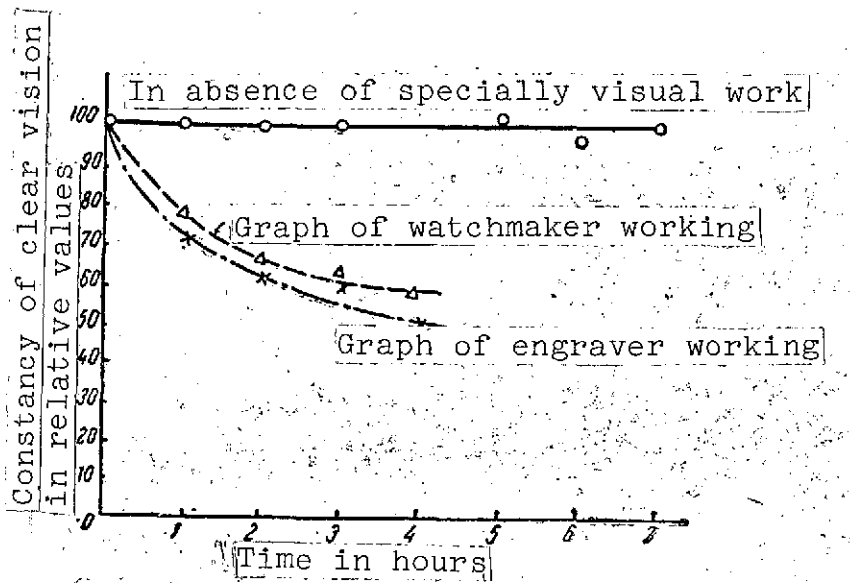


Figure 215. Constancy of clear vision and visual fatigue [Semonovskaya and Shubovaya].

Along the ordinate of the graph are the values for "the constancy of clear vision," along the abscissa — working time. The value prior to beginning work is taken as 100. The following graphs (Figure 216) can speak to the greater sensitivity of the method for determining "the constancy of clear vision" in comparison with methods for establishing the speed of visual perception or the usual means of measuring visual acuity. These graphs show how the functions of the eye depend upon wavelength (at a given light output). Along the abscissa, the wavelength is given in millimicrons, along the ordinate — the increase in efficiency of the corresponding ocular function in percent of the minimal efficiency. The constancy of clear vision, as we can see, is here a most sensitive index. To illustrate how the indices of this method respond to various changes in the condition of illumination, three more graphs are presented (Figure 217).

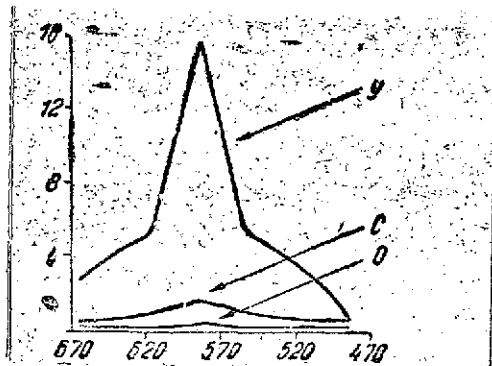


Figure 216. Constancy of clear vision (y), speed of visual perception (c), and visual acuity (o) as a function of wavelength [Ferree and Rand].

In graph A, the duration of an ongoing activity (reading) in hours is given along the abscissa, along the ordinate — the index of the constancy of clear vision as the relationship of the duration of clear vision to the duration of unclear vision, taken prior to working and afterwards. We

see here the effect of various means of illumination (all of equal light output): direct, producing the greatest decline in constancy; reflected, least fatiguing of all; and semi-reflected, occupying in this sense an intermediate position. In graph B, where the ordinate represents the same thing as in A, the abscissa shows the number of hours spent watching a movie screen. The fatiguing effect of various viewing distances on the eyes was studied. The lower line — a — was from a viewing distance of 7.5 meters, line b from a distance of 14.5 meters, and line c from 21.3 meters. Finally, on graph C, the abscissa gives the

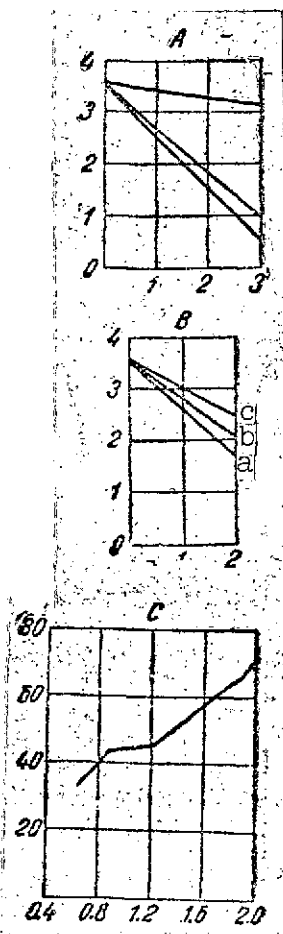


Figure 217. Decline of constancy of clear vision as a function of various conditions of working [Ferree and Rand].

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brightness (in candles per square inch) of various translucent armatures in which are located lamps; along the ordinate is given the percent of decline of the constancy of clear vision after three hours of working under the given armatures (with identical illumination on the working surface).

There remains, however, the open and unresolved question concerning the chief mechanism of affecting the results of similar experiments a la Ferree. Are they retinal changes or accommodation or convergence or simply the stability of visual fixation? The last would appear to be the most probable.

Undoubtedly, as Cholin notes on the basis of his own experiments, the general psychological fatigue of the subject affects, to a certain degree, the indices involved in determining the constancy of clear vision. However, the fact that the decline in the constancy of clear vision is paralleled by the greater or lesser perfection in the lighting conditions allows us, nonetheless, to regard it as an index of visual fatigue especially.

The method of determining the constancy of clear vision as outlined by Ferree and used to this day permits establishment of the degree of constancy of visual acuity in relation to some determinate object used as a test. It does not give us, however, a general picture of how our ability to see details changes for the duration of a more or less continuous length of time. In order to provide a more complete picture of the efficiency of the eye over the course of the entire experiment, Trukhanov proposes a new test representing a modification of Ferree's test. The subject is asked to look from a sufficient distance upon a figure-eight projected onto a black background by means of lines composed of light dots. Individual segments of these

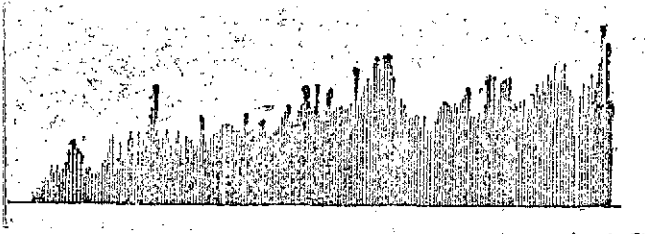


Figure 218. Displacement of the near point of convergence during repeated attempts to maximally converge [Berens, Hardy, and Pierce].

lines are composed of dots of different size, variously spaced from one another. Since the visual acuity of the subject does not remain constant during the test, individual segments of the figure will merge into solid lines or be seen as dotted lines so that various numbers are read by the

subject. As a result of whichever intervals between the white dots are indistinguishable for the subject at a particular instant, one may gauge the changes in visual acuity in the course of the experiment.

The stability of convergence and accommodation is studied /339
by means of a special "optical ergograph" proposed by Hoeve and perfected by Berens, Hardy, and Pierce. This "optical ergograph" permits the subject to bring the object (a black dot against a white background) until such time as there is subjective fusion. Movement of the object toward or away from the subject is recorded on a revolving drum. The experiments were based on the ability of the subject to keep his eyes in a maximally converged position, as well as on his ability to repeatedly converge and diverge his visual axes (Figure 218). Experiments conducted by the author up to this time have not studied the effect of visual fatigue stemming from some previous work. That which they have established refers only to the possibility of finding, by means of similar experiments, individuals with a weakened (against the standard) muscular apparatus in the eye.

A test of this method conducted by Holmskiy in the Institute of Labor Protection in Moscow showed that, for the determination of visual fatigue caused by visual work under any conditions of illumination, the method of optical ergography is not very sensitive.

Even the determination of the critical fusion frequency has been used as a means of measuring visual fatigue. Markstein has found that the critical frequency decreases after making difficult drawings. Snell found the same thing after looking at a flickering screen. The latter was confirmed in our experiments and in those of Mkrtychevaya.

In conclusion, we will refer to existing attempts to evaluate the quality of available lighting conditions by means of determining the visibility of an object with the aid of special "visibility measures" or visibility meters. Visibility meters have different systems. Some of them are based on the principle of decreasing the brightness of the object looked upon or on the extinguishing principle (visibility meters, suggested by Katz, Luckiesch, and Moss). Extinguishing of the brightness of the visual field is achieved by placing a neutral absorbing glass between the object and the eyes, thereby changing the coefficient of transmittance. Looking at the object through such a device and including the glass, which is absorbing more and more of the light, we darken the field of vision and may reach ...

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